How to make Portable Homemade Filament Extruder

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ABSTRACT	
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Abstract:

The main purpose of this thesis is to produce homemade filament extruder. The filament should be suitable for the use with FDM 3D printers. The dimension of the filament required is 1.75mm.The quality expected is the normal filament which should be able to feed on 3D printers. This extruder is especially for the 3D printer. The extrusion system only for the filament are not common and are only made by several makers and engineers around the world. The cheapest filament extruder on the market are still expensive comparing to the 3D printer itself. The normal price of extruder is around 2 times the price of 3D printer. This thesis project enables people to make filament extruder under 200 euro. The filament extruder that was used in Arcada UAS was too big and expensive for 3D printing purpose. The new homemade filament extruder would save lot of cost for those who need only filament for any purpose. Students, researchers and anyone who is willing to make their own filament can use this homemade extruder rather than buying a filament. This homemade extruder will be a portable machine so it is very easy to work with in office or while travelling. The extruder itself is small so, the maintenance cost for this extruder will be less. This thesis explains each steps that are needed to build the extruder.

Keywords	Filament extruder, 3D printer, plastic processing, recycling plastic:
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Abbreviation

CNC: Computer Numerical Control

ASTM: American Society for Testing and Materials

CROSS-WLF: Cross- (Williams-Landel-Ferry)

LDPE: Low Density Polyethylene

CAD: Computer Aided Design

CAM: Computer Aided Manufacturing

NC: Numerical Control

L/D: Length per Diameter

FDM: Fused decomposition modeling.

PTC: Positive Temperature coefficient

SSR: Solid state relay

PLA: Poly lactic Acid

DIN: Deutsches Institut fuer Normung

RMS Root mean square

PID: Proportional Integral Derivative

MFI: Melt Flow Index

MFR: Mass flow rate

MVR: Melt volume flow-rate

DC: Direct current

AC: Alternate current

Glossary

Shear viscosity: fluids' flow resistance to shearing action

Extrusion: a polymer processing technology carried out by pouring plastic pellet into hopper

Extrusion pressure: the pressure developed by screw pressure, which is area ratio of system and the screw; are responsible for filament to get out from the die.

Granules: palletized plastic particles produced as for raw material for plastic part production

Screw: a part of extruding unit the helps to melt and transport plastic from the hopper to die

Shear stress: a stress developed on a surface of an object due to force acting parallel to the surface

Shear rate: is a rate of shearing measured by the velocity gradient across the radius of a flow channel

Cooling time: the time it takes for an extruded molten plastic to solidify down to room temperature

Flow length: a length that a molten plastic flows through barrel under predefined set of conditions

Shear force: a force that makes the internal structure of a material to slide one over the other

Volume flow rate: a volume of fluid flowing through a certain cross-sectional area per unit time

Parameter: a set of measurable factors defining a certain operation system

Simulation: an abstraction of a real system made to benefit visualizing the real characteristic of optimized performance

Mastercam simulation: a software that gives an option of design, drill, mill and lathe simulation by generating NC machining codes for manufacturing

Calibration: the act of comparing and checking a process with a standard set of parameters.

Symbols

(Δvx/Δz or dvx/dz)= velocity gradient
“V” or “E”= A volt
C= current
T=torque
r=radius
F=force
C=capacitance
R = resistance
Q=charge flow
V= voltage
I= current,

FORWARD

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Helsinki, February 2015
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1. INTRODUCTION

1.1 Background

It is a good practice to perform analysis for any constructing design work in engineering world. Specifically, in the field of plastic engineering, extruder manufacturing is the core part of design and implementation. Plastic has wide range of machines which can be used to process. Viscosity, melt flow and size of the machine determines the predictability and manufacturability of the product. Designing and implementing the necessary design factures and proper knowledge on the machine parts should be studied well to ensure the optimization. Step by step process should be carried out to make it feasible. To make it real and working different working principles of the machine should be studied. The portable machine can be made by optimizing its uses. The machine produced may replace any bulky extrusion system .The Unnecessary over engineering may be corrected by making the extruder which can be used for specific purposes like making filament.

In the old days the designing used to be done in the papers without the use of computers. Due to the revolution in computer designing software, the designs in today's world is made on various software's like mastercam solidworks. .Including the design the software on computer are also able to analyze and simulate in virtual world to decrease the error. Every design which are made can be manipulated and tested without actually producing it. This system makes engineer easier to make product, study design, study manufacturability. The design software and simulation software both plays vital role in manufacturing of the product.

The computer software allows to design the various types of machine which the engineer dream of .the designed which are made can be easily manipulated in the present days. The engineering has become the revolutionized work now a days. The big hardware can be resized to the small size to decrease the usability and function ability. Every people who buys machine may or may not use the full function of the machine. The people may suffer by paying a lot of money for the things that don't even use it.

Filament Production is the process in which the plastic filament are made for the 3D printer. The filament production needs an extruder to produce the filament. In the present days there are not yet small portable extruders which can only make the plastic filament for this particular purpose. The filament should be able to be produced on smaller extruders. The extruder should be able to fit on the side of the 3d Printer to make it more comfortable .the filament should be made easily available by processing the plastic on small machine rather than buying it on the market. The test of the filament and the production quality will be tested by making this extruder.

1.2 Objectives

The major objectives of this thesis work are:

1. Design the extruder mechanism with necessary parts
2. Design the Heating system.
3. The automatic temperature control for the Extruder.
4. To test if it can be used on daily basis for long term use.
5. Replace 5 channel heating system with one channel.
6. Calculate die hole for filament.
7. Calculate the barrel size and screw size.

2. LITERATURE REVIEW

2.1 Extruder

2.1.1 Historical Development of Extruder

To extrude means the machine to push or force out the material through an opening to get product as the extrudate (Chris Rauwendaal, 2013) .The extruder was all about mixing the materials. The engineer Charles Hancock and his co-workers applied the fundamental principle of extrusion .in 1870s first screw machine was developed and in 1890s it was manufactured commercially in USA. In Europe Francis Shaw and Paul troester developed extrusion system commercially in 1900 (Crowther, 1998).

Extrusion Technology was introduced in late 1870, this has revolutionized the extruder system by accurate temperatures setting in extrusion. Due to this technology plastic deformation have been effectively reduced. The production of different thermoplastic polymers had also risen side by side. The extruder machines have only been able to process certain specific polymers. That is why the importance of designing and manufacturing extruder machines can incorporate and process the wide range of polymer types. From 1960 and onwards, the constant developments made in extruder machine manufacturing have been successful in this regard. The basic design of extruder machines did not change afterwards. In principle, every extruder machine follows certain mechanical procedure during production (Crowther, 1998).

The demand of plastic product raised with the development of extruder eventually, the next generation of the extruder was started when it was focused on die making. Those remarkable development made us able to look for the many customization for further needs. The compression and the pressure were studied together. Nowadays, the extruder has develop in many ways, the attention of the modern engineers changed its classical form to the modern form. The flight time of the extruder screw was increased co-rotating and counter rotating principle. Each design were noted for each use. The produced pressure were analyzed to develop the more advancement in the extruder (Taylor and Francis Group, 2011).

Recently, the extruder system are fully automated and there are huge development in extrusion system. This extrusion system have high in demand from pipes to the objects that are printed in 3D printer by using the same extrusion with the fusion of latest technologies. This development in this technology have two branches, the first branch has high efficiency and the other one has the development of finished product .It integrates surface technology and the use of Nano-technology. Starting from the wide range of extrusion technologies against the historical background, the new advancement are still running to produce sustainable/eco -friendly biopolymers such as PLA or Nano-composites (SAKAI, 2013).

2.1.2 Extrusion process

The process of extrusion is simple, and can be divided into six different processing steps:

1. Feeding
2. Melt
3. Melt conveying
4. Mixing
5. De-volatilization
6. Die forming

The extruding unit generally contains screw, barrel, heat control unit and the die, while extruding. Due to the gravitational force the resin or the plastic granules drops in the rotational screw of extruder. The screw rotates and creates friction which generates shear heat. In order to melt the plastic additional heating barrel are attached in the extruder. The electric heat control act as a thermal energy for the process. It also prevents the escaping of heat from the system by insulating the barrel radially nozzle through which molten plastic is injected through the die (Harod F.giles, 2005).

Then the molten plastic go through the small hole which is attached with a filter and plastic has to get through in order to get rid of impurity which then passes to die for customized final product. Extrusion is a continuous process of making or manufacturing products in large scale. It is very important to keep in mind the right operating control inputs and temperature measurements for required polymers and resins. The precise and satisfied product can o:nly be produced if every step in this process goes right. During this extrusion process, there might come many errors in final product, for example if temperature setting is not set properly or incorrectly, no matter how good resin is our product will be not as good as it should be.

Hopper

Due to the force of gravity granules reach to the system through hopper. The hopper are generally in funnel shape to make sure the granules can slide through the angled surface inside the hopper. The most hopper are attached by nut bolt system and are detachable to replace it with proper size according to feed needed in the system (Crawford, 2005).

Screw

The screw plays a vital role in extruding. The screw is needed to push the material which is feed to the system from the hopper. The rotating screw pushes the granules in to the barrel. The screw is the critical part to optimize .the improper design if the screw may result instabilities and improper product result. The speed of the screw can be determined from the control unit (Crawford, 2005).

Figure 1. Screw drill bit 16 mm Diameter

Barrel

The granules are heated through the five channels of heating using PTC or ceramic heaters in barrel. The granules are from solid state to liquid state mixing together. This is also known as heating and mixing zone. The friction force between screw and granules makes it easy to melt because the barrel temperatures gets high enough to melt the plastic. The molten material through the barrel gets into the holes of die where the shape of product is given (Crawford, 2005).

Die

The extruder contains breaker plate placed at the head of the extruder barrel which connects with the die. Gear pumps are also often placed in between die and the extruder for producing very uniform pressure, which produce uniform cross section dimensions. It provides a seal between the extruder and the die and due to it contains many holes the plastic are forced to pass in straight line after rotating movement during process. It also reduce other impurities to enter die. Dies are all replaceable and according to product requirement. The opening area of die is usually larger than the area to the finished side. Therefore die is a key unit of the extruder throughout the extrusion process (Crawford, 2005).

Control unit

The control unit is the device in which the each device is connected to operate. The analogue or digital control unit can control the production value .the speed and the heat in the barrel can be easily maintained by the help of this control unit. Simply it is the set of electronic connected together to make extruding easy. The production value and the power taken by the motor are also generally seen here in display panel of control unit. (Crawford, 2005).

2.1.3 Viscosity in Extrusion

Informally, viscosity is the quantity that describes a fluid's resistance to flow. Fluids resist the relative motion of immersed objects through them as well as to the motion of layers with differing velocities within them. Formally, viscosity (represented by the symbol η "eta") is the ratio of the shearing stress (ƒ/A) to the velocity gradient (Δvx/Δz or dvx/dz) in a fluid. (Elert, 1998–2015)

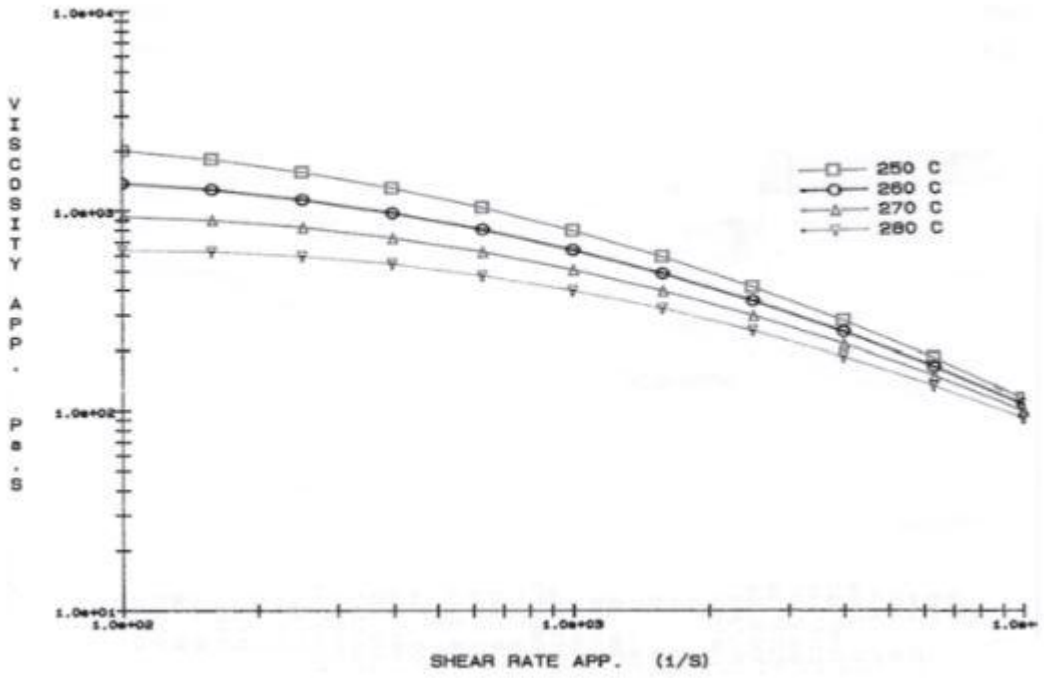

Figure 2. Capilary rheometry shear rate VS viscocity data (Harod F.giles, 2005)

Polymer viscosity is important in extrusion to understand the processing window, the role temperature plays in viscosity, and the importance of shear rate during processing. The viscosity versus shear rate curve shows large differences with temperature changes and only small differences with shear rate changes. To lower viscosity during extrusion, it is more effective to decrease the melt temperature. Going to a higher shear screw in either single or twin screw extrusion does not dramatically alter the resin viscosity. Higher shear rate does induce shear heating, which lowers the polymer viscosity and can lead to resin degradation. Some resin systems exhibit both strong temperature and strong shear dependence.

In these systems, while both temperature and shear have significant effects on viscosity, changes in shear rate affect viscosity more than changes in temperature (Harod F.giles, 2005).

2.2 Extruder Machine

The extruder machine nowadays are quite refined. The extruder are classified various different types depending the number of screws. There are basically 3 type's extruder

- Single screw extruder
- Twin screw extruder, and
- Multi-screw extruder.

2.2.1 Single screw extruder

Single screw extruder are the extruder which have only one screw in the system. It is commonly used for the simple and general materials. In recent years, people has done lots of research for more constant and stable extrusion. In extruder, material is mixed inside the barrel till the length of the extrusion machine.

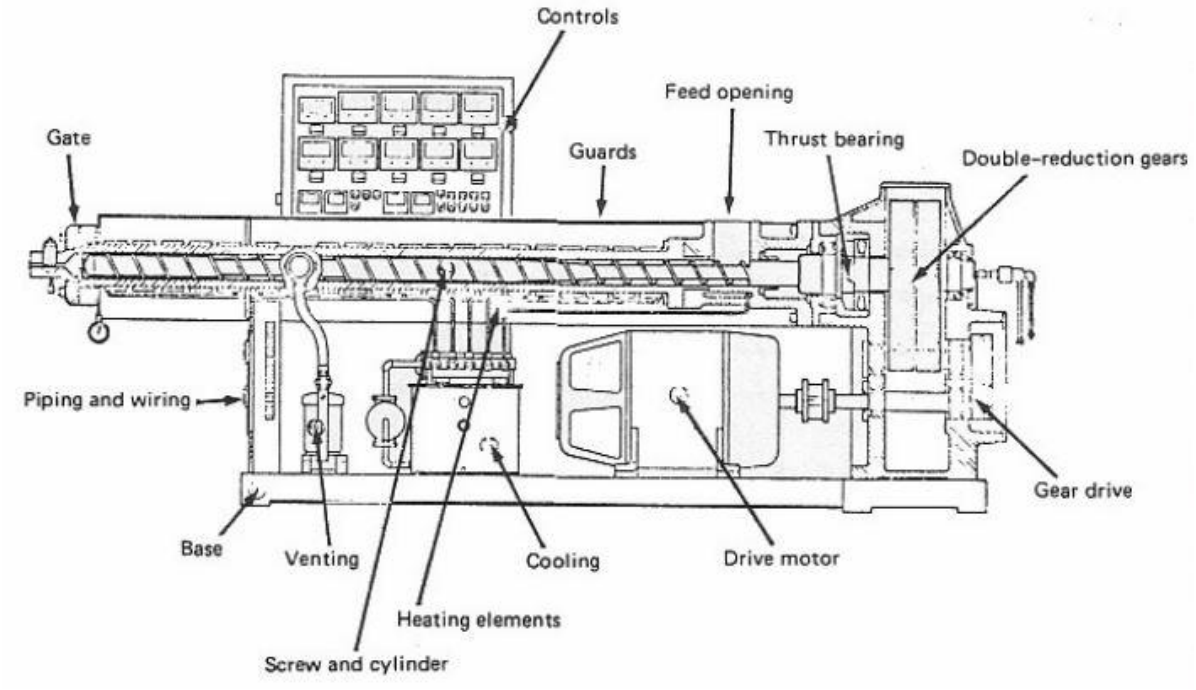

Figure 3. Single screw Extruder machine (welex inc, 2004)

2.2.2 Twin screw extruder

Twin extruder is generally used for powder processing. In this type of extruder, the powder are mixed according to the ratio. This extruder have better self-cleaning ability and mixing ability. The twin extruder is also used in the field of pelletizing the plastics. The performance which can be taken from twin extruder system is more qualitative.

Figure 4. Parallel twin screw (Harden, 2010)

2.2.3 Multi-screw extruder

The multi screw extruder is for the purpose in which we need more good output. The materials doesn't have mixing problem in this type of extruder. The output quality is very good and strong. This type of machine have more screw depending on the need of the uses.

2.3 Filament and 3D printer

3D printer is the machine which takes filament and use fused deposition modelling (FDM) or rip rap technology for making product. 3D printer makes a product layer by layer. The printing layer thickness in this printer vary from 0.01 mm to 0.04 mm. The filament used in 3D printer varies from 1.75 mm to 3 mm. With the help of support material it can print almost all type of product or its prototype theoretically. Some kind of support material can be easily removed by dissolving it in solvent to get final product. In this technology, the material cost can be reduced by adding infill like honeycomb, lines, concentric and rectilinear in hollow space. We can use 0.01 mm layer thickness in walls while manufacturing this product to get more strength. 3D printer Can also be other types .The other printer are liquid resign bases and powder resign based.

2.4 Stereo-lithography 3D printing or Laser sintering 3D printer

This is the method in which the liquid resins are cured or solidified by the use of laser beam scanned through it .The photosensitive polymers are solidified during this process. This forms the complex chained polymer object with great accuracy. (Bártolo, Paulo Jorge, 2011)

2.5 Density

“Density, a fundamental property, is defined as the weight per unit volume. It is normally measured in grams per cubic centimeter; however, bulk density and plastic density may be given as pounds per cubic foot” (Harod F.giles, 2005). In extrusion three different densities are critical:

- Raw material bulk density
- Melt density in the extruder
- Solid polymer density

The bulk density is important in determining whether potential feed problems may occur. A bulk density below 320.37 Kilogram per cubic meter is very fluffy and may not flow well from the feed hopper into the extruder. If it is free flowing, the feed volume per unit time may greatly reduce the anticipated throughput rate. (Harod F.giles, 2005)

The melt density is higher than the bulk density, as the air and space between the particles in the solid state are removed. In the melt state, the density is less than the final plastic part, as polymers contract as temperature decreases. In the final part, the molecular chains are tightly packed together and the air is removed that was originally present in the bulk density. Comparing high density and low density polyethylene in the same part, the high density polyethylene parts weigh more as the polymer atoms and molecules are more closely packed together in the higher crystallinity. Consequently, there is more mass per unit volume. Density is critical when buying resins for extrusion. The part volume is obtained by taking the circular area and multiplying it by the length. (Harod F.giles, 2005)

2.6 MFI (Melt flow index)

Melt flow index is also called melt flow rate, which gives the actual data or measurement of the flow of plastic resin. It represents the index for typical polyethylene and also for variety of materials for quality control in large production. The SI unit of MFR (Mass flow rate) is in g/10min. MFR can also be found by multiplying density of the plastic in melted state and MVR (melt volume flow rate). The Melt flow index are being used in different lab production field and quality control area. Melt density, manual timing, cutting and load of material gives the value of MFR. As many defined, classified, modern and semi-automatic machines which are available and based in displacement of piston gives higher accuracy flow rate of different material in molten state. The shear dependence of material depends on molecular mass distribution. It doesn't require very deep knowledge about the properties of materials if operator follows the Melt flow index (Plastics. Determination of the melt mass-flow rate (MFR) and the melt volume-flow rate (MVR) of thermoplastics, 2005).

2.7 Voltage

Voltage is defined as a potential difference between two points in electric field. If the voltage is high then the flow of electric current will also be high. Voltage is also known as electromotive force. The standard unit of voltage is volt and its symbol is "V" or "E". A volt carries charged electrons through resistance of one ohm in one second. A voltage also produces electrostatic field, even if there is no current. So when voltage increases the electrostatic field becomes more intense. A voltage which has same polarity is called direct voltage. If the polarity reverses direction then it is known as alternating voltage, it exists in the terminal of common outlet. A complete cycle in a second is called frequency which is generally measured in hertz (Rouse, 2005).

2.8 Current

Every matter consists of atom which has positive nucleus and some negative charged atoms. The current can be defined as a flow of charge. Coulomb is the standard unit of current and its symbol is C. The multiple of protons and electrons are known as charge. According to "Coulombs law", the influence of charges is characterized in terms of the forces between them. One coulomb charge is the charge which is required to flow through 120 watts bulb. The rate of flow of electric charge is called electric current and is measured in Amperes (Elert, 1998–2015).

2.9 Torque

The torque is the force which is required to rotate the object. The rotation can be in axis .The force and the distance between the axes is generally taken while calculating the torque. The distance between pivot and the in which the force acts is called moment arm. The motor that have high strength and can rotate despite of heavy resistance has more torque. Generally motor can be bought according to required torque.

And torque can be defined as

$$T = r\,x\,F = r\,F\,sin\,(\theta).\ (\text{Lawrence S. Lerner, 1996})$$

Where T=torque
r=radius
F=force

2.10 Friction

When the two surface comes in contact and have some corrosion, a force is created and that force is called friction. Friction compete against the motion of one surface across another surface. Friction cannot be created if there is only one surface, so in order to create friction it is depend onto two surfaces. The properties of the surface or the texture of the surface also gives the properties of friction. If the surface is very rough then there will be more friction. A factor affecting friction is also a contact force which pushes the two surface together and creates friction (Wagon, 1998).

2.11 The Drive

In the most of the extruder DC motor act as the core driving component. The AC has been replaced in the place of DC motor because AC are brushless and digital.AC motor can be easily optimized into 3-phaze system .Normally they are tied with pulley system to drive depending on extruder .the drive needs as much as the force to overcome the friction on the system between screw and the barrel (Chris Rauwendaal, 2013)

2.12 The bearings

The bearing was introduced in the mid-1740s by horologist John Harrison for his H3 marine timekeeper. The bearing is used to reduce friction between moving parts to desired motion. It reduces friction by controlling the vectors of the different force. In the extruder bearing system, it contains circular and axial bearing. The goal of this bearing is to provide resistance support for the screw, even at the high speed (Barr, 1966).

2.1.2.1 Limits and Fits, Tolerance dimensioning

Normally when the parts are designed it should be capable of fitting. The parts cannot be forcefully put in together to make any product which may cause accidents. So, there are several rules in designing which defines the basic size, nominal size or the design size. The design precision depends on the number of decimals after the measurement i.e.: 1.2922mm this means the precision is needed much more to fulfil this required dimension but if the size is 1.2 mm then we have more limits.
There are several rules on all fittings for efficiency. Engineers can easily determine the allowance to fit the shaft in circular fits. So the basic fittings system is taken in to use for greater accuracy. These are the things which engineer should know and consider while designing. The assembly part cannot succeed if this limits and tolerance are not matched. So this is about using standard values during fittings (Limits and Fits, Tolerance Dimensioning).

2.13 Electrical Heaters

Electric heaters are used in extruder, these heaters has replaced other fluid heaters or steam heating systems. Electrical heaters are widely used nowadays because it is very efficient and cost reducing. It is not expensive to maintain in comparison to other heating systems. In the extruder, if the extruder machine is small ad has fewer zones then they have few heaters and if the machine is big and many zones then it has more electric heaters. Electric heaters usually covers a large area then other heating system. It has become an engineer friendly hating system in extruding process (Chris Rauwendaal, 2013).

The certain amount of current passes through the conductor which has certain resistance, these resistance works as barrier in the flow and generates the heat. The heat obtained by this is given below in the equation.

$$QC = I\,2R = VI = V2 / R$$

(Where, C=capacitance R = resistance Q=charge flow V= voltage and I= current, respectively) (Chris Rauwendaal, 2013).

This equation is used in both AC and DC current and expressed in RMS (root mean square)
For three phase circuit heat equation is given by

$$QC = 3VI$$ (Chris Rauwendaal, 2013).

2.14 Air Cooling

The process of cooling the filament with the help of air is air cooling. The air-cooling can be done with the help of fan. The small CPU fan can be easily used if cooling is needed. This make the molten plastic filament to cool down to avoid extra shrink of the plastic filament.

2.15 Solid state Relay (SSR)

SSR is the device in which the temperature can be controlled with the help of PID. For controlling the electric circuit to maintain the temperature. The temperature can be controlled by controlling electricity. So this device acts as the gate keeper for the electricity .Which means when the temperature is insufficient the SSR will transmit electricity to the heater and when the temperature reaches the required level it cuts of the electricity with the help of PID and thermostat (Metro physics inc, 1964).

Figure 5. Solid state Relay

2.16 PID controller

PID is the device which provides the Information to SSR when to turn on and when to turn off. ID reads the temperature of any system with the help of thermostat. It functions as the input panel to the system (Metro physics inc, 1964).

Figure 6. Pid Controller

General-purpose of temperature controllers are used to control most typical processes in industry. Typically, they come in a range of DIN sizes, have multiple outputs, and programmable output functions. These controllers can also perform PID control for excellent general control situations. They are traditionally placed in the front panel with the display for easy operator accessibility. These controllers have a pre-tune function to initially calculate the PID temperature for a process, and a continuous tune function to constantly refine the PID temperature. This allows for quick setup, saving time and reducing waste." (Total Temperature Instrumentation, Inc., 2015)

2.17 Thermocouple

The sensor which is used to measure the temperature is known as thermocouple.it consist of two wires made from different metals. When the two material are subjected to the heat, it produces some electric voltage which determines the reading of the temperature in the system. The thermocouple are used for low cost, durable and high temperature range (Metro physics inc, 1964).

Figure 7Thermocouple

2.18 Mastercam

Mastercam is the software which is developed by CNC Inc.it is popular in manufacturing markets by using CAD/CAM methods. It is the software which helps design the object with The CAD-CAM operation .The model can be designed or imported from the other designing software's. This software enables us to generate g-codes which is needed for the CNC machine. We can generate and edit these G-codes as per need-codes are the travel path of the milling drill bits (CNC Software, Inc, 2014).

2.19 Solidworks

Solidworks is the software which offers a complete tools needed for the designing.it makes the imagination come to reality. Engineers can make better product by using this software. In this software the engineers can work with different planes which makes them most creative (SOLIDWORKS Corp., 2015).

2.20 Motor (Drive system)

The DC motors are the powerful motor nowadays. They can give three to four and even five times more torque on emergency situations. In dc motors the energy is fed to resistor can result the stopping application in various fields. And controlling the rotations .This makes remove or reduce mechanical brakes size. This can be controlled both in clockwise and anti-clockwise and from rest to motion in short interval time, without the use of power switch. This motors can run continuous without an expiry date. The rotation per minute of motor changes to drive system.

2.21 PTC heater

The heater made with PTC chips are one of the modern device in electronix.it does not use wire as the resistance but instead of that it uses number of chips of ceramics. It manufactured from a barium-titanate material plus a few key doping materials to provide the desired resistance. When electrical voltage is applied to a PTC chip, heat is NOT generated at a constant rate. Rather, as the PTC chips heat up they reach a designed temperature at which the heat output decreases drastically and prohibits the heater from getting hotter. Thus, PTC chip shave a designed temperature limit.PTC chips inherently limit the temperature of the electric immersion heater and thus do not require over temperature protection. Basically the over temperature protection is built into the heater core, offering key advantages over traditional resistance heaters (Dulzer, 2008).

2.22 Kapton tape

Kapton tape is made up of high temperature series polyamide film, this polyamide tape is used in different electronic manufacturing process, like soldering, masking of circuit boards, transformer and capacitor insulator, powder coating and other high temperature applications. Kapton tape contains polyamide material and silicone adhesive which makes it a choice of many engineers because it does not leave any residue. It is very highly heat resistance tape which can take up to 260 degree Celsius. This can be used for insulation purpose in the extruder.

2.23 Compression Ratio

The ratio of channel depth in feed and metering zone is called compression. This ratio is considered as a very important parameter in the field of screw design. One is called depth compression ratio and other is called volumetric compression ratio. The compression ratio is in use instead of depth compression ratio.

The compression ratio is given by,
CR = Channel depth in feed zone / channel depth in metering zone.
(Where, CR = Compression Ratio)

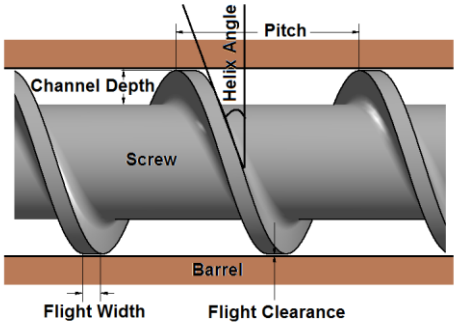

Figure 8. Basic property of plasticating screw (Hassan Eslami, 2015)

The screws like barrier screw are special ones, therefore to consider the volumetric compression is more important and reliable for design parameter than depth compression ratio. In designing these screw, the flight pitch is also changed from feed to the transition and metering zones (Hassan Eslami, 2015).

2.24 Length-over-diameter (L/D) ratio

The length over diameter (L/D) is also one of the important measure in screw design. The ratio generally are found between 20:1 to 34:1 of any typical screw. The ultimate application of the screw is responsible to determine its length. So length of the screw is depend on, each turn while designing the screw. For typical extrusion there are three zones, feeding, compression and metering zones. Therefore conventional screw generally have L/D ratio of 24:1. Besides conventional screws application, there are other fields of application where high pressure, heat and constant temperature is required in order to process the material. In film casting process too, it is very important to have homogenized and gel free melt in constant heat and temperature. Therefore for such application the extra sections are added while designing the screw. The general L/D ratio for film extrusion is 30:1 (Hassan Eslami, 2015). After knowing the Length-over diameter, it is possible to find out how long is the barrel.
The length-over-diameter ratio is defined as:
$L/D = Screw\ flighted\ length\ /\ screw\ outside\ diameter$ (Hassan Eslami, 2015)
The advantages of using long and short extruders are given below:

Table 1. Advantages of long and short extruders

	Advantages Short Extruders		Advantages of Long extruders
1.	Required floor space is less,	1.	Capable of more mixing,
2.	Low initial cost of investment,	2.	Can pump at higher die pressure,
3.	Low replacement cost for extruder parts	3.	Good Melting capacity with less heat,
4.	Less torque is required	4.	More conductive heating from barrel
5.	Less horsepower and small motor size	5.	Higher output is related to the screw design.
6.	Output is related to L/D of extruder.		

3. Method

The length of the extruder built was about 500 mm in length. During the making process the concept of the extruder were studied analysed. The possibility was been tested. They should be able to recycle the plastics which is found around the house. The plastics should be grinded before feeding to this homemade extruder. The filament produced from this filament extruder should be able to feed on the 3d printer. This could enable people to use the plastic whether it is TV or the fridge or even plastic bags that are used daily. This thesis work will list all the materials needed for the construction of the extruder. The different assembly of the extruder will be designed. The necessary body will be milled in cam software .the HAAS system will be used .The heating system used will be also discussed. The feed system and use of available resources as a die. This system can be completely made on home and only some few electronics part could be bought from the market. The proper temperature control system will be established with the screw replaced by auger.

This thesis does not include any instruction on Hi-tech extruder. This is just done if somebody wants to produce their own filament for their 3D printer using pallets and shredded plastics. This product will be only for home use.

3.1 Approach

By studying all the theories it is concluded that plastic can be processed by eliminating five channels heating as the most of the plastic melts below 240oC.
The main idea is to maintain the temperature in the barrel and extrude the filament. Temperature of 220°C should be able to melt the plastic. The torque of the drive shaft should be able to provide enough torque to rotate screw. The Pressure created on the barrel should be able to push the material from the die with the hole of 1.5mm.

The most of the component which is needed can be easily bought in any country. The extruder can be made on home with little cost .This extruder that I am making is definitely cheap than the other 5 channel heating system extruder.

3.2 3D printed method

The process can be also done by using full 3D printer method. For this process the base has to be designed in the computer and can be printed from the 3D printer. This type of method is safer and doesn't require HAAS milling. The Idea is to make the solid base from the 3D printer to attach the different component in it. After printing the Solid base the Process should be faster than any other method.

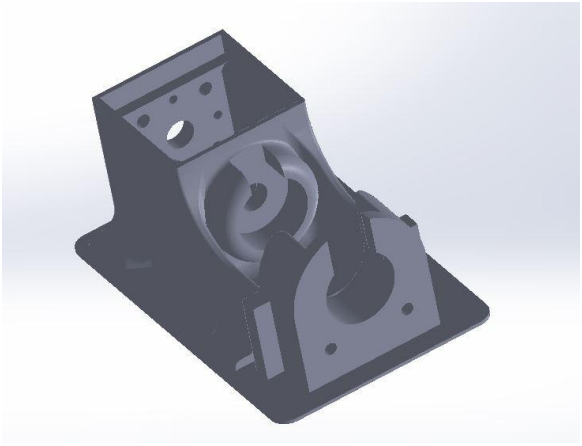

Figure 9. 3D printed base

3.3 Construction Process

The outer shell of old gear box of the bigger motor was taken as the base of the extruder. The shaft was removed and replaced with the 16mm internal diameter and 20mm outer diameter threaded steel tube .The tube was perfectly pushed inside the shell of the gear box. The one side of the tube was wrapped with kapton tape along with the thermocouple for measuring the heat and to know the information of temperature changes on the tube. After setting up the thermocouple, heater was set after three layer of Aluminium coil was wrapped. Another three layer of aluminium coil was wrapped on same tube to make uniform heat distribution along the tube. Then a layer of kapton tape and the Aluminium foil was wrapped at last to make insulation. The glass fibre was surrounded to the heating system and aluminium to provide sufficient insulation and stable temperature the last insulation of glassier is also done to make it more efficient.

The wood auger drill bit was used as a screw. The auger was attached with a coupler to the shaft of the motor the screw was driven by an AC Motor of 220v which have the rotation of 5RPM. The motor was bought from internet.

The die was custom made using the water stopper with the hole of 1.5 mm diameter and was attached to the extruder using its threaded line.

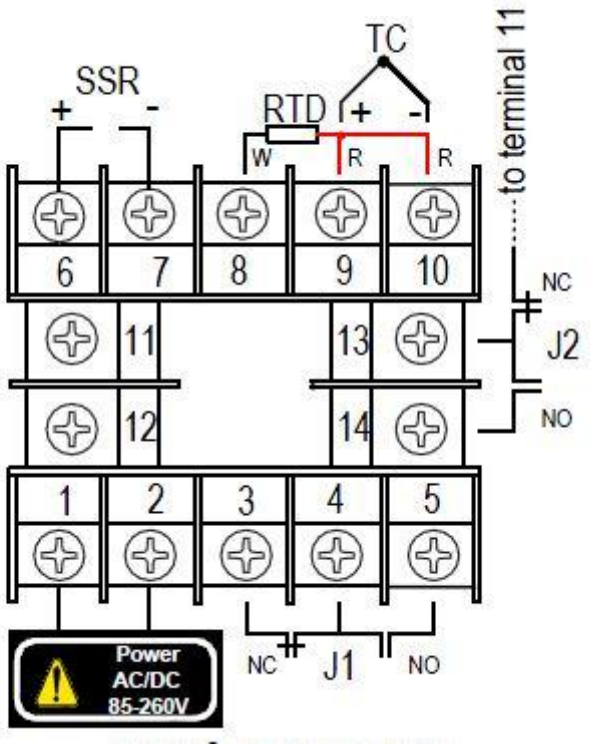

Figure 10. PID wiring diagram

The thermocouple was connected to the port 9 and port 10 .This port was the place where heat sensor was connected. It was able to read temperature of tube after connecting. SSR is connected on port 6 and port 7 according to polarity. This was able to switch the heater on and off after obtaining required temperature. The main power supply of this extruder is port 1 and port 2. The power supply for the heater was also supplied through port 1 and port 2.This completed the electronics wiring of the heat control mechanism.

After the assembly of the extruder parts was completed. The machine was left 30 min with turning on the heat of 217 ^{0}C. After acquiring the stable temperature the motor in drive system was turned on .The pellets were then poured in to the hopper. The motor was on the speed of 5 RPM .the plastic were driven by the screw along the barrel. When the plastic reached the heating section it started melting and the pressure was created inside the tube. Due to the friction inside the Steel tube and the additional heating from the heater rises the temperature and melted the plastic completely. The filament was extruded through the die hole of 1.5 mm in diameter.

Figure 11. Die with 1.5 mm hole

3.4 Cooling a Filament

Cooling the filament is also one of the important part of the extrusion process. A better cooling system helps to obtain high quality smooth filaments. There is natural cooling effect in which are left on the floor to cool down hot filaments coming out from extruder. Beside this process an additional fan can be added to cool down the temperature of filaments when it comes out of the die.

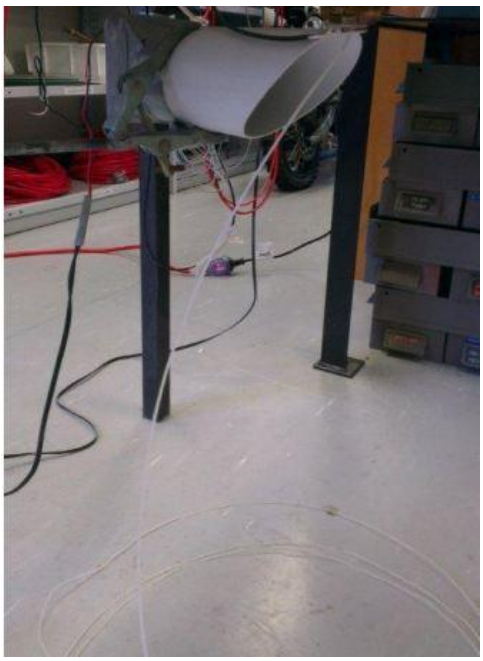

Figure 12. Cooling Fan- in Filament

Figure 13. Natural cooling effect on floor

4. Results

The investigation showed that extrusion of plastic filament of comparable quality to commercial filaments is possible with careful operation. The diameter is the most critical feature and is dependent on the rate at which the filament is drawn away from the die as well as a steady input to the heating pipe. With an out feed mechanism, the filament could be drawn at constant rate to form a constant diameter.

If a large amount of raw plastic is placed in the hopper, this causes the Plastic in the hopper to begin melting and clog the inlet to the pipe. Also, the melted plastic cannot be removed from the pipe if the pipe and plastic is allowed to cool. Finally, after long operation the frame of the extruder becomes hot through contact with the heating pipe. The following result were obtained after the extrusion of the filament.

I. The plastic from the die failed to came from 1 mm diameter hole. The pressure created on the empty space before die was unable to push it. After making 1.5 mm diameter die the pressure was created on die hole and extrusion was possible.
II. The inside diameter of the barrel and the outside diameter of screw was 16 mm which assume to be perfect for the filament of 1.5 mm.
III. The heating process with one channel heating system was enough for the melting process.
IV. The insulation was not that enough to make temperature stable on short barrel below 250mm.
V. The temperature of the barrel fluctuate $\pm 30^0$C.
VI. The plastic melt around the screw was observed and it was constant.
VII. The plastics which has melting point lower than 2000C was possible with this kind of extruder .The plastic which melts above 250^0C can be also extruded but needs better insulation with more heat.
VIII. The cooling system is required for the motor for longer use and optional for short use.

Figure 14. Extrusion carried out without using Die

Figure 15. Produced plastic filament using 1.5 mm Die hole

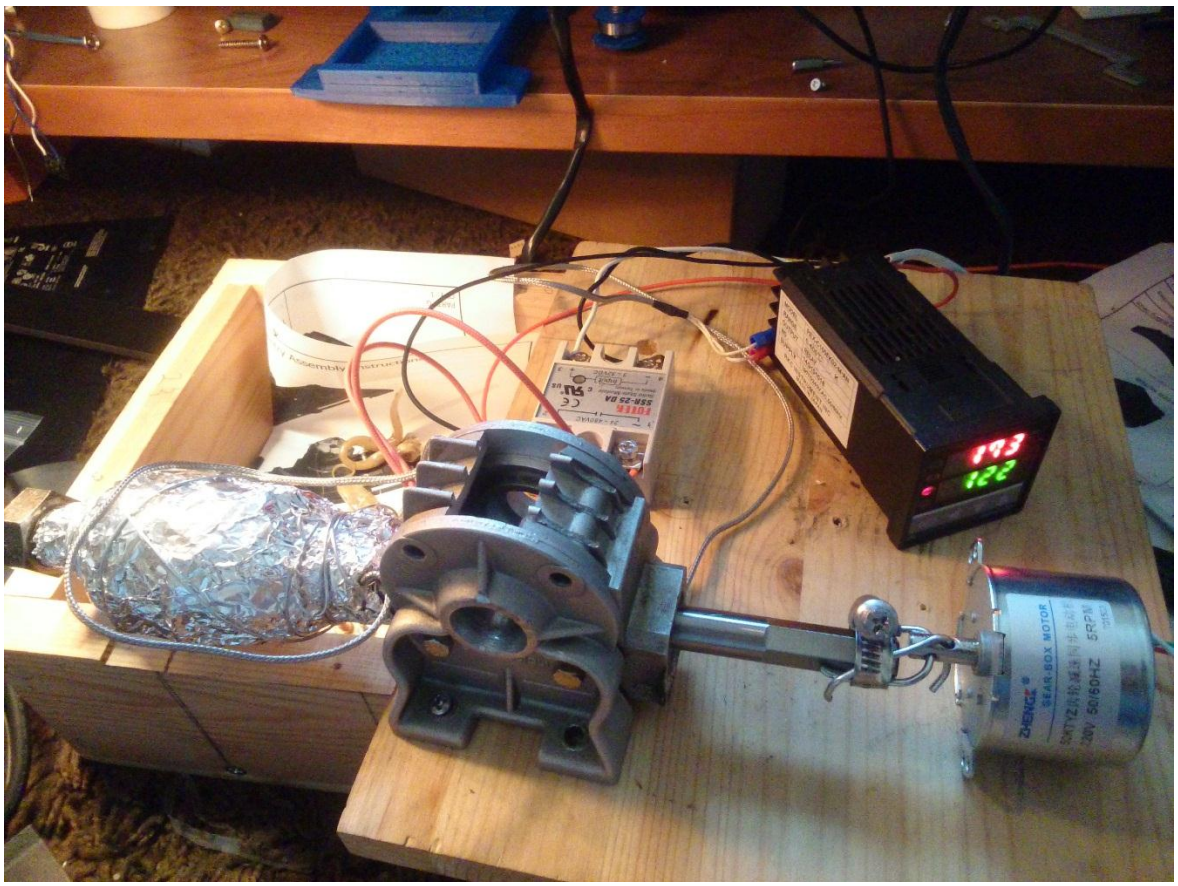

Figure 16. Assembled homemade extruder

4.1 Expected Results

This is the typical home extruder. The full automation is not be expected. The heater should be turned on and the proper temperature should be inputted in the PID- controller. The minimum time to stabilize the temperature is 30 minutes. The extrusion can be started after the temperature becomes stable. The pellets or shredded plastic should put on the hopper .The speed of the motor is fixed so stable filament should be obtained.

The expected result is the high quality filament with uniform diameter. The filament size should be range from 1.6mm to 1.75mm.The bubbles and roughness on the filament are not expected.

4.2 Financial calculation and Analysis

As the purpose of this project is to make affordable home made extruder which can be used in order to obtain filaments feeds for the 3D printers. The following table shows the expenses over buying different parts during the making of the extruder machine.

Table 2. Financial Calculation

	Name of the parts	Value	Purchase
1.	Heater	6 Euro	Self
2.	Steel pipe threaded	20 Euro	Self
3.	SSR	18 Euro	Self
4.	Motor	12 Euro	Self
5.	Aluminium wire	2 Euro	Self
6.	PID controller	30 Euro	Self
7	Wood Screw drill bit	15 Euro	Self
	Total	103 Euro	

From the table above we can analyze that this machine can be made cheaper. The overall purchased part of this extruder are relatively cheaper than the big extruders. This shows that there is still market for small extruders which can make only filament for 3D printers. The price of the parts may differ from place to place. Many people can take advantage of this machine in low price with low maintenance cost.

4.3 Comparison with Other extruder

Table 3. Comparison of Filament extruders

1	Strooder Extruder	£249 without VAT and shipping.
2	Filastruder Extruder	$309.99 + 45$ shipping
3	Filabot Extruder	$949 + shipping
4	The Noztek Pro Extruder	£ 794.95+ Shipping

The above table shows that the extruder which are available in the market are relatively expensive than the home made extruder. Some of the extruder in the list are only available for pre-order. The price offered in above table are from their official site.

5. Conclusion

During the extrusion process in homemade extruder the filaments came out nice and uniform. The proper heat and correct temperature setting during the process gives the high quality filaments. However if the temperature is not according to the material that is being processed the obtained filament will be rough and uneven. If the temperature is too low for material then some plastic pellets will not melt properly and it cause the bubble and the roughness in the filaments as a result. In these situations, to control the consistency of plastic melt inside and to have a good flow, the speed of the motor can be decreased to the required temperature. Then the plastic pellets melt uniformly and slowly with enough heat which results a good, even and high quality plastic filaments. While carrying out tests it showed that, the prototype could extrude good quality filament with the motor AC power supply set to 230V and the temperature in excess of 200°C. The melting point of the Polystyrene pellets is use for the experiment .The size of the filament is determined by the size of hole on the die and the speed at which motor rotates. For the efficient operation the hopper and the heating zone should be isolated. The lack of isolation may result in molten plastic on hopper and can experience clog on the system. The heat produce can melt raw material before going to barrel. The cleaning of screw can be done time to time by taking it out and heating and the remains of plastic melts away and same applies for the barrel. This type of extruder becomes more efficient because it is very cheap to replace the parts. This can be considered as the cleaver use of available parts. This can help society to learn new way of reusing and recycling things made either out of plastic or metal.

6. Discussion

The laws of physics can be implemented in each steps to make extruder more efficient. These includes torque, gravity, friction and heat. Each component plays vital role in working mechanism. The idea was to recycle the thrown away things of plastics and re ruse using simple home machine. This recycling of electronics components, heaters led lights etc. encourages people to make different things which is useful to them. Using this homemade extruder, one can easily recycle useless plastic in home and can generate good filaments, which can be used in 3D printers to print different parts which is desired. It is also possible to print different part of the extruder like hopper, base and other supporting plastic frames to make homemade extruder more strong nice and light weight. Many people does not have access to advance machine like HAAS machine, lathe. Which are comparatively very expensive to buy, if the requirement is only to generate filaments. So, this machine could help everyone who wish to recycle thrown away plastic at home and make their own feed for the 3D printers. This machine can be highly advantageous for researchers, designers and students to carry out their field of research.

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